

Cardiovascular system

- The heart is formed of two separate pumps.
 - Rt heart : volume pump against low resistance.
 - Lt heart : pressure pump against high resistance.
- Each pump is composed of two chambers.
 - Atrium : functions mainly as a blood reservoir.
 - Ventricle : main pump of bl. in pulmonary or systemic circ.
- In mammals, 2 cardiac pumps are connected to two circulations.
 - Major (systemic) circulation: carries oxygenated blood.
From Lt ventricle to tissue then back to Rt atrium.
 - Lesser (pulmonary) circulation carries deoxygenated blood.
From Rt ventricle to lung then back to Lt atrium.

Note Lymphatic system carries excess nonabsorbable tissue fluids (lymph) to veins via thoracic and right lymphatic ducts.
- Cardiac valves are of two types
 - Atrioventricular (A-V) valves are mitral (bicuspid) & tricuspid valves
 - Semilunar valves are aortic and pulmonary valves

Notes All valves are tricuspid except mitral valve is bicuspid.
Papillary muscles are attached to leaflets of A-V valves by coronary tendinae.
When " " contract they pull the cusps of valves towards the ventricle.
- Cardiac muscle fibres = cardiac cells = myocytes are of two types:
 - Ordinary contractile muscle fibres of atria and ventricles -
Cells full of contractile muscle proteins.
 - Specialised muscle fibres for initiation and propagation of C. impulses.
Cells with few contractile muscle proteins.
 - Pace makers : SA node, AV node or Purkinje fibres,
 - Conducting muscle fibres e.g Purkinje system.

12/08/25

VISIT...

LANZAROTE
Caliente.COM

Cardiac muscle proteins

Like skeletal ms, in cardiac muscle sarcomere is the functional unit.

In addition to myosin, actin, tropomyosin & troponin, cardiac ms contains also

Titin (largest known ptn)	Dystrophin.
Very large elongated elastic ptn Binds myosin to Z line. Keeps myosin in centre of sarcomere Congenital defect → dilated heart	A large protein Connects actin to extracell. matrix (ECM) Provides structural support to m. fibres Congenital defect → muscle weakness

Cardiac cells myocytes 75% of total volume of myocardium.

- Enveloped in extracell. matrix (ECM) which is strengthened by fibrillar collagen.
- Contain contractile ptns in myofibrils (50-60% of cell volume).
- Rich in mitochondria 30% of cell volume in adult.
- Cardiac cells in atria or ventricles act as one unit i.e. functional syncytium ; because of intercalated disks (tight intracellular connection).

Functions of the intercalated disks :

- 1 Connect 2 adjacent cells.
- 2 Connect actin filaments of adjacent cells at Z lines.
- 3 Provide a strong union between fibres to transmit contraction between them.
- 4 Contain gap junctions which allow electrical connection between cardiac cells.
Each gap junction is composed of several channels of low resistance which allow flow of ions and Δ potential between adjacent cardiac cells.
 - Less gap junctions in AV node causing slow conduction.
 - More „ „ in Purkinje's ventricular fibres → rapid conduction.

Cardiac conduction system is formed of

1 Sinoatrial node (SA) node	2 Atrioventricular node (AV) node
located in Rt atrium at superior vena cava Discharges most rapidly 90-105/min It is the normal cardiac pacemaker Inhibited by Rt. vagus.	located in Rt post part of interatrial septum Discharges less rapidly 40-60/min Only conducting pathway between atria & ventricles & continues as bundle of His (2)

3 The bundle of His : continues as Rt bundle branch RBB.
It gives off Lt bundle branch (LBB) at the top of interventricular septum.
The 2 branches run subendocardially & give rise to

4 Purkinje Fibres (system) to all parts of ventricular myocardium.

Notes Atrial muscle is separated from ventricular muscle by fibrous ring.

The myocardium is covered by epicardium & lined by endocardium.

The " is enclosed in pericardial sac which contains lubrical fluid (5-30 ml)

Cardiac properties

All cardiac properties are myogenic i.e don't depend on external innervation.

① Excitability & electrical properties :

• RMP in ventricular cells = -85 mV . Caused by:

① Selective permeability

Potassium leak out of myocytes via inwards rectifying potassium channels which does not inactivate with time (nongated).

$$E_K = -98 \text{ mV}$$

$$E_{Na} = +64 \text{ mV}$$

② Electrogenic Na^+-K^+ pump creates -4 mV difference.

Notes Rectification = ion movement in one direction.

Inward current = influx of +ve ions (Na^+ or Ca^{++}) to inside of cells

→ depolarization.

Outward current = efflux of +ve ions (K^+) to outside of cells or influx of -ve ions (Cl^-) → repolarization or hyperpolarization.

IRK channels is named inward rectifying; because at mem. potential less than -85 mV e.g -90 mV (hyperpolarization) it conducts inward current.

However, in cardiac cell hyperpol. doesn't occur under normal condition.

so IRK channels conduct outward current I_{K1} i.e K^+ efflux.

$\ominus\ominus$ or $\oplus\oplus$ in extracell. K^+ conc. → partial depol i.e $\oplus\oplus$ excitability

• Depol. by high K^+ is explained by Nernst equation

③

• Depol by very low K^+ is explained by slow Na^+-K^+ pump.

Action potential transient depol followed by repol.

Depol is followed by repol; because the mem. resists any change from polarised state

Monophasic action potential: ventricular or atrial

- Recorded by placing an electrode inside & the other outside the cells
- Duration Long A. potential (Atrial 200 & Ventricular 300 msec)
- Description and ionic basis 5 phases

Phase 0: Rapid depolarization and overshoot.

Cause Activation (opening) of fast voltage gated Na^+ channels.
They conduct rapid inward current (I_{Na}) $\rightarrow$ rapid depol.

- All outer gates are opened at -65 mV i.e. firing level
- Inner gates close and terminate the upstroke at +20 mV

Phase 1: Rapid repolarization to +10 mV

- Cause
- 1 Rapid inactivation of I_{Na}
 - 2 Activation of transient outward (TO) currents caused by efflux of K^+ and influx of Cl^-

Phase 2 Plateau Unique to cardiac cells.

Cause Balance between

- 1 Inward Ca^{++} currents viz long lasting (L type) Ca^{++} channels
- 2 Outward K^+ currents.

Terminal part of plateau is prolonged by inward current viz electrogenic Na^+/Ca^{++} exchanger (one Ca^{++} ion out per 3 Na^+ ions transported into the cells).

Significance of long plateau:

- 1 Provides sustained long depol & contraction to empty the heart.
- 2 Prevents premature reactivation i.e. prevents tetanus.
- 3 Allows the heart to complete its cont & relax before the next activation.

(4)

Note L type Ca^{++} channels are the main Ca^{++} channels in heart. Voltage gated ,, which inactivate very slowly.

They conduct inward current I_{Ca-L} . Influx of Ca^{++} triggers the release of Ca^{++} from (SR) which is called Ca^{++} induced Ca^{++} release (CICR).

Channels are blocked by dihydropyridine (DHP) drug.

Phase 3 Repolarization

Cause As the time dependent inward Ca^{++} current is inactivated the outward K^{+} currents (I_K) rapidly repolarize cells to -40 mV. I_K occurs via delayed rectifying K (DRK) channels which are . Voltage gated activated at -40 mV during depol. . and deactivated at -40 mV during repolarization.

Phase 4 RMP

Cause Inwards rectifying K current I_{K1} drives the cells towards RMP i.e -85 mV via inward rectifying K channels (I_{K1}).

Notes Changes in extracell. Na^{+} conc. affects magnitude of action potential. Increased extracell. Ca^{++} conc. increases myocardial contractility.

Aim of vent. A. potential. is to maintain entry of Ca^{++} & CICR mechanism.

• Excitability changes during action potential

1 <u>Absolute refractory period</u> ARP	2 <u>Relative refractory period</u>
Excitability <u>0</u> coincides with <u>phase 0, 1, 2 & 1st $\frac{1}{2}$ of 3</u> i.e all <u>systole & early diastole</u> Tetanus <u>can't</u> occur.	Excitability is <u>subnormal</u> coincides with <u>last $\frac{1}{2}$ of 3 phases & 4</u> i.e <u>part of diastole</u> . Early premature cont (extrasystole) can occur.
3 <u>Vulnerable period</u> It coincides with <u>1st part of diastole</u> . Stim. of heart during this period may produce <u>fatal ventricular fibrillation</u>	Excitability is <u>supernormal</u> (5)

- Relation between the A. potential & cardiac contractile response
 Contractile response lasts above 1.5 times the action potential
Systole begins just after the start of depolarization.
ends (reaches its maximum) by the end of plateau.
Diastole begins with the third phase (repolarization)
Repolarization is completed by the end of 1st half of diastole

② Rhythmicity (Automaticity)

Sinoatrial (SA) node is the normal pacemaker (Highest rhythm)
 SA node initiates repetitive regular action potentials.

Pacemaker currents

Normally only in SA node 90-105 and AV node 40 to 60/min.

If SA & AV nodes are depressed or blocked, there are latent pacemakers in Purkinje fibres 30 (15-40) minute.

Depolarization spreads from SAN to other parts of the conductive system before they discharge spontaneously. So, SA node normally controls HR
 Heart rate is 70 to 75 beats/min; because of the inhibitory vagal discharge.

Nodal action potential:

Compared with ventricular action potential.

- 1 The membrane potential is unstable.
- 2 Most important is the presence of spontaneous diastolic depolariz. in phase 4 of action potential.
 It starts at -65 mV
 Activation threshold (firing level) -40 mV
- 3 It has slower upstroke; because of absence of the fast I_{Na}
- 4 Apex of action potential reaches only +10 mV
- 5 No Plateau.

⑥

Four pacemaker currents explain spontaneous diastolic depolarization

1 Gradual disappearance Delayed rectifying potassium current I_K
During repolarization phase: I_K becomes inactivated gradually at -40 mV and then decays (disappears) after a while.
 I_K allows SA nodal potential to reach -50 mV or less then disappears

2 Inward current (Funny current) I_f
Activated when SA node is hyperpolarised (-50 to -90 mV)
It is caused by influx of both Na^+ ions (with concentration gradient) & K^+ ions (against concentration gradient)

3 Background inward current (I_b)
 I_b remains when all currents are blocked
It is caused by spontaneous inward movement of Na^+ ions (with conc. gradient)

4 Slow inward nodal calcium currents I_{Ca}
 I_{Ca} explains the slow depolarization phase of action potential.
It can be separated into:

- Transient component I_{Ca-T} activated at -50 mV by spontaneous diastolic depolarization and followed by
- Long-lasting component I_{Ca-L} activated at -30 mV

The presence of 4 pacemaker currents is a safety factor which insures the depol. function of SA node, even if one current is inhibited.

Autonomic control of SA node

Stim. of vagal fibres to cardiac muscle

→ -- rate of nodal discharge - ve

Acetylcholine via muscarinic M_2 receptors

→ ++ K^+ conductance → hyperpolarization

Stim. of symp. fibres to cardiac muscle

→ ++ rate of nodal discharge +ve chronotropic

Norepinephrine via β_1 → ++ cAMP

→ open L type Ca channel → Depolarization

N.B Heart rate is ++ by temperature rise i.e. fever.

Heart rate is -- by digitalis (cardiac glycosides).

③ Conductivity Spread of cardiac excitation.

Depolarization initiated in the SA node spreads along internodal tracts through the atria then along AV node, to bundle of His, to Purkinje system to ventricular muscle.

Velocity of action potential is determined by:

- The speed of upstroke of the action potential
High in ventricle. Slow in nodal tissues
- The intercellular resistance i.e. number of gap junctions.
More in Purkinje system Less in nodal tissues $\rightarrow$ slow conduct.

Tissue	Conduction rate m/second
SA node & AV node	0.05
Atrial pathway, bundle of His and ventricular muscle.	1
Purkinje system	4

Note Atrial depolarization is completed in 0.08 - 0.1 second.
Ventricular depolarization is completed in 0.08 - 0.1 second.
Sympathetic stim. shortens the AV nodal delay
Vagal stim. & digitalis lengthen the AV nodal delay.

Importance of AV nodal delay: 0.1 second

- It allows sufficient time for atria to empty their blood into ventricles before the start of ventricular systole.
- It protects the ventricles against the high pathological atrial rhythm e.g. atrial fibrillation.

Importance of the very rapid conduction in the Purkinje system:

It allows all ventricular muscle fibres to contract as one unit and at one time.

Mechanical properties "contractility"

Excitation - Contraction Coupling:

Like skeletal muscles, except these differences:

- Contraction is an example of Ca^{++} Induced Ca^{++} Release (CICR).
 Na^+ current has rapidly initiated Ca^{++} influx via $\text{I}_{\text{Ca}^{++} \text{ L}}$.
 Ca^{++} entering the cytoplasm from extracellular space triggers Ca^{++} release from SR via RyR (Ca^{++} channels).
Note L type Ca^{++} channel blockers e.g DHP reduce contraction i.e -ve inotropic effect.
- Relaxation is produced by lowering Ca^{++} via 3 mechanisms:
 - a Ca^{++} is pumped back into SR by ATP dependent Ca^{++} pump.
 - b Ca^{++} is transported out of the cell by $\text{Na}^+ - \text{Ca}^{++}$ exchanger.
 - c Ca^{++} binds to Ca^{++} intracellular buffering ptn (calmodulin).
- Finally, Ca^{++} release process is recovered by $\text{Na}^+ - \text{K}^+$ pump before the next contraction.
- Unlike sk ms, activation of cardiac muscle by Ca^{++} (CICR) is normally below maximum i.e change in Ca $\rightarrow$ change in contractility

Correlation between muscle fibre length and tension:

A Passive length - tension curve

Progressive ++ in length of a resting muscle by adding weights (preload) without stimulation $\rightarrow$ progressive ++ in passive or resting tension.

B Active length - tension curve

If a muscle stretched by preload is stimulated to contract isometrically $\rightarrow$ ++ tension without shortening

Result Peak tension $\propto$ resting muscle length

Starling law of heart Force of contraction of cardiac muscle

Inotropic
Def: Intra

is directly proportional to resting length of cardiac muscle within limits.

Mechanism Increased initial length of muscle leads to:

- 1 increased number of cross-bridges.
- 2 increased affinity of troponin C to Ca^{++} .

NB Muscle contracts isometrically then isotonically, so tension is 1st increased then becomes constant.

Afterload the tension at which the load is lifted.

Performance of isolated cardiac muscle is affected by 4 major factors:

- 1 Resting muscle length (preload).
- 2 The level of afterload.
- 3 Inotropic state contractility.
- 4 Frequency of contraction.

Performance of cardiac muscle can be measured by:

- 1 Extent of shortening (ΔL)
- 2 Velocity of shortening dL/dt

Preload and Afterload effect is studied on 2 cardiac function curves.

on isolated cardiac muscle 1 1 Length tension curve

- Length - shortening curve At the same level of afterload, progressive ++ in preloads $\longrightarrow$ progressive $\oplus\oplus$ in ΔL within limits

- Load - shortening curve At the same level of preload, progressive ++ in afterloads $\longrightarrow$ progressive $\ominus\ominus$ in ΔL

N.B ΔL = initial muscle length - shortening muscle length.

2 Load - velocity curve At the same level of preload, progressive ++ in afterloads $\longrightarrow$ progressive $\ominus\ominus$ in dL/dt

- P_0 is the peak isometric tension at zero velocity
i.e the muscle is unable to lift the weight.

- V_{max} is the velocity of muscle shortening at zero load
determined by extrapolation (theoretical point)

At any level of afterload, the muscle is faster and can shorten more at higher preload.

Inotropic state (contractility)

Def: Intrinsic ability of myocardium to contract independently of changes in preload or afterload.

CICR is normally below maximal i.e. there is Ca^{++} reserve to increase (+ve) or decrease (-ve) the level of myocardial contractility.

Inotropic state is demonstrated in length-tension & force velocity curves.

1 Length-tension curve

At the same level of preload and afterload,

+ve inotropic stimulus $\rightarrow$ more ΔL & vice versa.

2 Load-velocity curve

At the same level of preload and afterload,

+ve inotropic stimulus $\rightarrow$ faster contraction & vice versa.

Frequency of contraction (force frequency relation)

Stair case or treppe phenomenon:

++ Frequency of stim. $\rightarrow$ +ve inotropic state by changing Ca^{++} release & uptake

++ rate of stim. produce initial slight drop in developed force followed by progressive rise in force of cont. and vice versa.

In the whole intact heart:

- The length of muscle fibres is proportional to end diastolic volume.
- The tension developed is proportional to pressure developed in ventricles.
- The developed tension $\propto$ diastolic volume (within limits).
i.e. ascending then descending limbs of Starling curve.
- The preload = end diastolic volume (EDV) i.e. stretch before contraction.
- The afterload = end systolic pressure = aortic pressure. i.e. the resistance against which blood is pumped.
- The frequency of contraction = Heart rate.

Electrocardiogram ECG

Definition Record of rapid voltage changes of heart

2 skin electrodes i.e. Biphasic AP. Body fluids are good conductors

Recording of ECG:

1 Apparatus a Monitoring machine viz CRO used in ICU

b Recording machine fed to heat stylus open recorder on a moving calibrated strip of paper.

Small square 40 msec i.e. 25 squares/sec = 1500 squares/min

Small square 0.1 mV.

Vector = an arrow represents sum of electrical activity.

Vector represents

Direction of vector

Atrial activity

Downwards & to Lt

Septal activity

Upwards & to Rt

Vent. activity

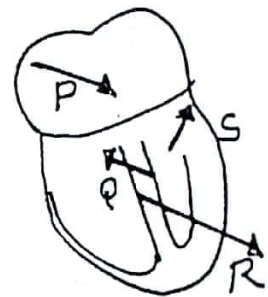
Downwards & to Lt

Base of Lt vent

Upwards & to Lt

Length of vector

$\propto$ mass of tissue



Duration

$\propto$ $\frac{1}{\text{velocity of conduction}}$

Polarity

If Dep. is directed towards +ve electrode $\rightarrow$ +ve wave

If Repol. is directed " +ve " $\rightarrow$ -ve wave since

If vector is parallel to lead $\rightarrow$ maximal effect

perpendicular to lead $\rightarrow$ not recorded

Lead position of the 2 electrodes or actual recording

According to TYPE of electrodes, leads may be:

1 Bipolar leads between two exploring electrodes (-ve & +ve)
e.g. Standard limb leads

2 Unipolar leads between one exploring electrode (+ve electrode) and one indifferent -ve electrode conducted by connecting simultaneously to the 3 limbs (Rt arm, Lt arm & Lt Foot) to resistance 5000 ohm.

g. 1 Augmented limb leads One +ve electrode attached to a limb. , the other electrode is attached to the other two limbs Potential is 50% more without affecting configuration of the record.

2 Unipolar chest leads precordial leads V_1 to V_6

3 Esophageal lead rarely used to record post. surface of atria

N.B Rt leg is considered earthing electrode.

V (unipolar) a (augmented) L (Lt arm) R (Rt arm) F (Lt foot)

☒ Bipolar leads (standard limb leads)

	Exploring -ve electrode	Exploring +ve electrode
1 Lead I	R	L
2 Lead II	R	F
3 Lead III	L	F

☒ Augmented unipolar limb leads

	Exploring +ve electrode	Other electrode
1 aVR	R	LF
2 aVL	L	RF
3 aVF	F	LR

☒ Unipolar limb leads

	Exploring +ve electrode	Indifferent electrode
V_1 Rt 4th space parasternal		RLF
V_2 Lt 4th space parasternal		RLF
V_3 between V_2 & V_4		RLF
V_4 5th space midclavicular line		RLF
V_5 5th space ant. axillary line		RLF
V_6 5th space mid axillary line		RLF

N.B Einthoven triangle heart at its centre

Approximated by putting electrodes at R, L & F.

Zero potential if the 3 electrodes are connected to indiff. electrode

Normal ECG

Intervals = Waves + Segments

Waves	P	QRS	T	U
Represents	A. depol.	V. depol.	V repol.	Papillary m. repol.
Duration (width)	0.08 - 0.15 i.e 80 - 100 msec	0.08 second	0.16 second	0.05 sec.
Voltage (height)	- Limb leads 0.25 mV - Chest leads	1 mV 3 - 4 mV	> 0.5 mV > 1 mV	Usually not recorded
Shape	1st half for Rt atrium 2nd half for Lt atrium	V ₁ , V ₂ small R, Large S V ₃ , V ₄ Moderate R, S V ₅ , V ₆ large R, small S	Slightly rounded & asymmetrical	
Direction	Inverted in aVR	R always +ve Q -ve before R S -ve after R	Inverted in aVR	

NB - A. repol.: masked by QRS complex very low voltage.

- Depol. of SAN, AVN & Purkinje f. not recorded (small mass of tissue).

- Q wave Depth $< \frac{1}{4}$ (1-2mm) Width < 0.04 sec.

Pathological Q wave i.e large Q wave indicates myocardial infarction

Q normally appears in Lead I, aVL, V₅ & V₆

Disappearance of growing R from V₁ to V₆ = serious vent. condition.

Variation in voltage of QRS helps in diagnosis of vent. enlargement

Increased duration of QRS helps in ,, of bundle branch block.

- T wave (repol) in same direction of R wave (depol) because last part to be depol. (epicardium) is the 1st part to be repol.

During systole, compression stress -- bl supply & delays repol. in subendoc.

Segments

- P-R segment 0.08 to 0.1 second

Measurement From end of P to beginning of QRS

(14)

represents Conduction through A-V node

- S-T segment Normally isoelectric i.e same level of T-P line.

Elevation of ST segment above isoelectric line by 2-3 mm is the most significant abnormal finding in recent myocard. infarction. It coincides with plateau of monophasic vent. A. potential. (0.32 second) i.e it coincides with vent. repolarization.

Intervals

- P-R interval

- [Measurement beginning of P wave to beginning of QRS complex
- [Represents A depol. plus conduction in A-V node.
- [Normal 0.16 to 0.20 second average 0.18 sec i.e 180 msec
- [Prolonged in A-V block 1st degree H. block
Atrial enlargement
Vagal stimulation
- [Shortened in A-V nodal rhythm
Sympathetic stim.

- Q-T interval

- [Measurement beginning of QRS complex to end of T wave
- [Represents Vent. depol. plus Vent. repol.
- [Normally 0.04 second
- [Prolonged e.g. Hypocalcemia

Comments on normal ECG

- 1 Heart rate HR $\frac{1500}{\text{number of small squares between 2 successive R}}$
normal 60-90 /min. average 75 min
- 2 Rhythm almost regular i.e duration between R waves nearly equal
- 3 Voltage of ECG normal summation of QRS voltage in standard limb lead
Normally, $\gg 1.6 \text{ mV}$ i.e 16 mm
- 4 Axis of the heart = mean instantaneous vector of QRS complex in L_1, L_2 axis

Vector is algebraic sum of A. potential at a particular point
Each P wave, QRS complex & T wave has a vector.

Normal calculated axis of heart is -30° to $+90^\circ$

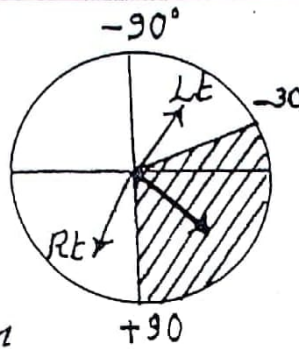
Rt axis deviation

QRS -ve in L I
+ve in L III

Axis From $+110^\circ$ to -90°

Physiol. Long slender person

Pathol. Rt vent. hypertrophy (RVH)
Rt bundle branch block (RBBB)
Lt. vent. infarction



Lt axis deviation

QRS +ve in Lead I
-ve in Lead III

Axis From -30° to -90°

Short stunted person

Full term pregnancy

Lt. vent. hypertrophy (LVH)
Lt. bundle branch block (LBBB)
Rt. vent. infarction

N.B Relationship of vent. monophasic A.pot. to ECG:

QRS coincides with rapid depol.

T wave " " rapid repol

ST segment " " plateau

Relationship of cardiac contraction to ECG:

P wave occurs before the beginning of atrial cont. by 0.02

QRS complex " before " " ventricular cont. by 0.025

Ventricle remains contracted until after end of T wave

ECG abnormalities

A) Disorders of rhythm

1. Simple sinus tachycardia

HR 100 - 150/min

Fever $0.5^\circ\text{C} \rightarrow \begin{cases} +8/\text{min} & \text{adult} \\ +10-15/\text{min} & \text{child} \end{cases}$

Symp stim.

A-V nodal rhythm (if SAN is damaged)

P inverted or absent & short P-R interval

Simple sinus bradycardia

HR below 60/min

Athletes at rest (high vagal tone)

Vagal stim. in carotid sinus syndrome

(16)

AV rhythm ← PR → short → ventricle
 3521' 3 Atrial Flutter regular $200-350 / \text{min}$
 P: QRS 2:1 or 3:1
 i.e. incomplete heart block
 QRS at regular intervals
 4 Vent. extrasystole Vent. premature beat (VPB)
 Cause Ectopic vent focus discharges occasionally due to
 excessive smoking, coffee drinking or alcohol & lack of sleep or abdominal
 distension
 ECG P absent
 QRS giant, bizarre and prolonged.
 T inverted
 Compensatory pause follows VPB
 3521' 3 Atrial Fibrillation irregular $300-500 \text{ per min}$
 P waves are absent & replaced by F waves
 QRS at irregular intervals
 4 Vent. extrasystole Vent. premature beat (VPB)

B) Disorders of conduction

- 1 Atrio-ventricular block i.e. lesion in A-V bundle.
1st degree All atrial impulses are conducted to ventricle.
 but with difficulty prolonged P-R interval
2nd degree Some impulses are conducted others do not
 Atrial beats (P) : Vent. beats (QRS & T) 2:1 or 3:1
3rd degree (Complete heart block) No atrial impulses are conducted
 Ventricles beat independent of atria at slow rate
 i.e. idioventricular rhythm 35-45/min
 There is complete dissociation between P waves and QRS & T.
- 2 Bundle branch block (BBB) Lt or Rt bundle lesion
 Excitation passes through muscle to activate vent. on blocked side
 Vent rate normal QRS complexes are prolonged & deformed

C) Low voltage ECG i.e. normal summation of QRS complexes
 in L_1, L_{II} or $L_{III} < 1.5 \text{ mV}$ ($< 15 \text{ mm}$)

Cause Obesity (body mass index BMI > 30), pleural effusion
or hypothyroidism (myxedema)

High voltage ECG sum of QRS in L_1, L_{II} or L_{III} $> 3.5 \text{ mV}$ ($> 35 \text{ mm}$)

D) Lt vent. hypertrophy (LVH)

Lt axis deviation

S in V_1 or V_2 + R in V_5 or V_6

35 mm in adults

45 mm in children

Rt vent. hypertrophy (RVH)

Rt axis deviation

Reversal of precordial pattern i.e.

- tall R in V_1 & V_2

- Deep S in V_5 & V_6

E) Myocardial infarction

Cause -- bl. supply to part of myocardium irreversible changes
and death of muscle cells

1 Acute myocardial infarction

Elevation of S-T segment of infarcted area in the 1st hour.

2 After some days or week S-T elevation subsides

Pathological Q ++ in size and width of Q wave

F) Electrolyte imbalance

1 Hypokalemia Flattening or inversion of T wave
& prominent U wave

Hyperkalemia Tall, thin T waves

2 Hypocalcemia prolonged Q-T interval.

Hypercalcemia shortening Q-T interval.

Cardiac cycle

Period From beginning of one H. beat to beginning of next beat
 A-V delay (0.1s) allow Atrial cont. emptying before Vent. cont.
 C. cycle consists of a period of relax (diastole) & cont. (systole).

During diastole: Heart rest, coronary bl. flow to subendocardium of Lt. vent occurs and most of ventricular filling occurs.

	HR 75/min.	HR 200/min
Duration of C. cycle	0.8	0.3
„ Vent. systole	0.3	0.15
„ Vent. diastole	0.5	0.15

If heart rate $\uparrow\uparrow$, diastole is shortened more than systole.

HR up to 160 as in exercise leads to increased cardiac output
 Above 160/min, filling is decreased and cardiac output decreases.

C. cycle 8 phases & 8 changes look table page

Notes Some regurgitation of bl. into veins occurs during atrial systole.

Vent. systole starts by cont. of intervent. septum pulling on fibres around the A-V valves closing them & resulting in 1st heart sound.

Late in systole, aortic p exceeds vent. p. for a short period. Momentum (kinetic force) keeps blood moving forwards.

Main function of atria is bl reservoir & not to pump blood; because 70% of vent. filling occurs passively. So, atria are not essential for life.

Pressure - volume graph of Lt ventricle 4 phases

Phase I Period of Filling

During diastole, The ventricle fills passively

- Filling pressure for Lt. vent is pulmonary venous pressure
 for Rt. vent is RAP i.e. central „ „
 = 5 mmHg (between 3 & 7 mmHg)

2012/08/25

19

12/11/14

Page

	Late diastole		Ventricular Systole		Early diastole	
	1 A. systole	2 Isometric isovols cont.	3 Maximum (rapid) ejection	4 Reduced ejection	5 Proto diastolic	6 Iso metric (isovol.) relax.
1 Ventricular Pressure	0.1 (++) due to A. systole then (-) due to V. diastole	0.05 (++) to 80 mmHg Lt V. 10 mmHg Rt V. ends by opening of semilunar valves	0.15 (++) to maxim. 120 mmHg Lt V. 25 mmHg Rt V.	0.1 (--)	0.04 (--)	0.06 (-- to 0 mmHg Lt V. 0 mmHg Rt V.)
2 Ventricular Volume	Increased > 30% ED 130	Constant	Decreased rapidly	Increased slowly	Constant	Increased rapidly
3 Aortic Pressure	C a t a c r o t i c Blood leaves aorta to peripheral vessels	Ascending an aortic BI ejected in aorta BI enters aorta > BI leaving aorta 120 mmHg	D e s c e n d i n g	D i c r o t i c notch: sudden closure of aortic valve	Constant	Increased rapidly
4 Atrial Pressure	+ve Atrial closure systolic opening	+ve Bulge A-V cusp	-ve Decline	Accumulation of VR in atrium		
5 A-V valves	open	C	L	O	S	D
Semilunar	C=1=0	S=e=d	open	open	open	C=1=0
6 Heart Sounds	4th HS vent. filling by A. systole	1st HS sudden closure of A-V valves long low pitch	2nd HS closure of aortic valve	3rd HS rapid vent. filling		
7 ECG	P starts 0.025 before A cont	QRS starts 0.025 before V. cont	T wave begins	T wave peaks		T wave ends
8 Coronary bl. flow		MINIMUM	Slight ++ with aortic p	Slight -- with aortic p		MAXIMUM

20/10/22

• Vent. volume increases to 130 ml i.e EDV called preload
Phase II Period of isovolumetric contraction.

- Vent. pressure rises from 0 to 80 mmHg for L vent.
- Vent. volume is kept constant (130 ml); as vent. cont. isovolumetrically & moves from diastolic to systolic compliance curve

Phase III Period of ejection

- Vent. pressure exceeds aortic p. & aortic valve opens
 - " " rises to a maximum of 120 mmHg then it $\rightarrow$
 - Vent volume decreases from 130 to 50 ml (ESV)
- Contraction changes suddenly from isometric to isotonic

Phase IV Period of isovolumic relaxation

At end of ejection, aortic valve closes & vent relaxes isometrically
Plot moves vertically from systolic to diastolic compliance curve

- Vent pressure falls to zero i.e below atrial p. mitral valve opens
- Vent. volume is kept constant (50 ml) i.e ESV

N.B From curve, Stroke volume = $EDV - ESV = 130 - 50 = 80 \text{ ml}$

Arterial pulse

Blood forced into aorta sets up a pressure wave which expands the arterial wall as it travels. Expansion is palpable as pulse

- Velocity of p. wave 7 meter/sec. while bl velocity in aorta 0.5 m/s
- In elderly, arteries are more rigid so pulse wave moves faster.

The pulse is felt in radial artery at wrist 0.1 s after ejection peak.
Strength of pulse $\propto$ Pulse pressure i.e Systolic P. - Diastolic P.
Pulse is weak (thready) in shock & strong in exercise.

Atrial pressure changes

Atrial p. changes are transmitted to great veins e.g. jugular vein (JV) producing 3 pressure waves

a wave is due to atrial systole.

c wave is due to rise of atrial p during isometric vent. contraction.

v wave is due to rise of atrial p before AV valve opens during diastole.

Heart sounds HS

Four HS

Two sounds are normally heard by stethoscope during cardiac cycle:

	First heart sound	Second heart sound
<u>Cause</u>	Vibrations set up by the A-V valves	sudden closure of <u>Semilunar valves</u>
<u>Time</u>	Diastole end (start of systole)	<u>Systole end</u> (start of diastole)
<u>Best heard at</u>	Apex of heart (5th Lt space midclavicular (mitral com.) Lower end of sternum (tricuspid component)	<u>Second Rt costosternal junction</u> (aortic component) <u>Second Lt intercostal space parasternal</u> (pulm. component)
<u>Characters</u>	<u>Longer</u> 0.15 second isomet cont & max eject. <u>Low pitch</u> 25-45 Hz <u>LUB</u>	<u>Short</u> 0.12 second isometric relaxation <u>High pitch</u> 50 Hz <u>DUP</u>

A.B In male (mitral area) 10 cm (3.5 inch) from middle line below Lt nipple.

Physiologic splitting of 2nd HS: During inspiration, time between aortic & pulm. valves closure is long enough for 2nd HS to be reduplicated.

Time between 1st & 2nd HS = Systole & between 2nd & 1st HS = Diastole

Two HS are normally non-audible by stethoscope.

Third heart sound	Fourth heart sound
May be heard in <u>young</u> during diastole Coincides with <u>rapid filling</u> (rush of bl.)	<u>Rarely</u> heard in normal adult Due to vent. filling during <u>A. systole</u>

Murmur Abnormal noise sounds heard over the heart

Mechanism Change of bl. flow from laminar flow (silent) to turbulent flow (creates sounds) This occurs when blood exceeds a critical velocity
eg when a heart valve is narrowed.

Major cause is valvular diseases

Cardiac output COP

Definitions

- Stroke volume Vol. of bl. pumped by one ventricle per BEAT
 $SV = \text{end-diastolic vol.} - \text{end-systolic vol.}$ $SV = EDV - ESV$
- COP (minute vol.) Vol. of bl. pumped by one ventricle per MINUTE
 $COP = SV \times HR = 70 \text{ ml} \times 70 \text{ beats/min} = 5 \text{ Litre/min}$
- Cardiac index COP per square meter surface area $= 3.2 \text{ L/min/m}^2$

Measurement

1 Direct Fick method

Fick principle $F(\text{flow}) = \frac{\text{Amount of substance taken by organ}}{\text{Arterio-Venous (A-V) difference}}$

$$COP (\text{of Rt vent.} = \text{Lt vent.}) = \frac{O_2 \text{ consumption in mL/min}}{A_{O_2} - V_{O_2}}$$

$$= \frac{250 \text{ mL/min}}{190 \text{ mL/L} - 140 \text{ mL/L}} = \frac{250 \text{ mL/min}}{50 \text{ mL/min}} = 5 \text{ L/min}$$

Arterial O_2 content is measured in a sample taken from any artery
Venous bl. sample is taken from pulm. artery by cardiac catheter

2 Indicator dilution technique

Indicator : Dye (cardiogreen) or Radioactive isotope. is injected IV
Not harmful, has no haemodynamic effect & not excreted rapidly

$$CO = \frac{\text{Amount of indicator}}{\text{Average conc. of indicator}} \times \frac{60}{\text{Time of first passage}}$$

Average conc. of indicator & time of 1st passage are known from the concentration-time curve by plotting the log of indicator conc. against time. in a serial arterial samples
Log of indicator conc. is used to eliminate big variations in concent.

The conc. of indicator rises, falls then rises again due to recirculation

3 Thermodilution technique - same principle of indicator dilution.

Indicator : Cold saline injected in Rt atrium by double lumen catheter

Indicator

Blood temp. changes in pulm. artery is recorded using a thermometer in the other longer side of the catheter.

Advantages 1 Saline is completely harmless.

2 No second rise i.e. recirculation is not a problem.

4 Doppler combined with echocardiography: non-invasive technique.

Various conditions that affect COP

Increased

Excitement & anxiety 50-100%

Exercise up to 70%

Eating 30%

Exposure to high atmosph temp.

Epinephrine

End of pregnancy

Decreased

Sitting or standing

From lying
20-30%

Rapid arrhythmia

Heart diseases

No change

Sleep

Moderate change in
atmospheric temp.

Factors affecting performance of whole heart (same as isolated ms)
i.e. preload, afterload, inotropic state and heart rate.

Control of cardiac output

1 Venous return: which is primarily affected by peripheral circulation
In the steady state: $VR = COP$

2 Cardiac performance.

Venous return curves & COP curves explain the interplay between 2 factors:

Venous return

Guided by Ohm's law $Flow (F) = \frac{\text{Pressure gradient } (\Delta P)}{\text{Resistance } (R)}$

$VR = \frac{MSFP - RAP}{RVR}$ i.e. 3 factors affecting VR

1 MSFP

Mean Systemic Filling Pressure

2 RAP

Right Atrial Pressure (Central Venous Pressure (CVP))

3 RVR

Resistance to Venous Return

venous filling pressure = MSFP - RAP is primary determinant of VR

1 Mean Systemic Filling Pressure (MSFP)

Def. P in systemic circulation when blood flow is stopped. or simply P in veins as capacity of veins is 18 times that of arteries
It can be measured in heart-lung preparation if the pump oxygenator which replaces the heart is stopped.

Normally 6 - 8 mmHg. It represents distending p. of all vessels

$$\text{MSFP} \propto \frac{\text{volume of blood}}{\text{vol (capacity) of vascular system}}$$

2 Right Atrial Pressure (RAP) i.e central venous pressure (CVP)

Venous return (Venous Function) curves :

VR is plotted against RAP (RAP normally 0-2 mmHg)

$$\boxed{\text{VR} \propto \frac{1}{\text{RAP}}} \quad \text{refer to curve}$$

• Down slope ++ RAP $\rightarrow$ -- VR VR = 0 when RAP = MSFP = 7 mmHg

• Plateau occurs as RAP becomes less than -1 mmHg

-- RAP $\leftarrow$ ++ ΔP $\rightarrow$ ++ VR
collapse of intrathoracic veins $\rightarrow$ -- VR so VR $\oplus$

• Transitional zone between down slope & plateau

Increased blood vol or venoconstriction shifts VR curve upwards (i.e.)
i.e increased VR & vice versa

3 Resistance to Venous Return (RVR)

++ RVR shifts VR curve downwards (i.e.) i.e -- VR & vice versa

$$\text{RVR} = \frac{\text{MSFP} - \text{RAP}}{\text{VR}} = \frac{7 - 0}{5} = 1.4 \text{ mmHg/L/min.}$$

Most of RVR occurs in veins; accordingly sudden drop of COP & fainting occurs if VR -- by mild compression of inferior vena cava.

Cardiac output curve :

COP is plotted against RAP

$$\boxed{\text{COP} \propto \text{RAP}} \quad \text{within limits refer to curve}$$

Guided by Ohm's law, if COP in heart-lung preparation is adjusted at 5 L/min & systemic resistance at 20 mmHg/L/min Mean ABP (diastolic + $\frac{1}{3}$ pulse p) will be 105 mmHg refer to base

Systemic venous filling p = MSFP - RAP = 5 mmHg

Cardiac output (curve) is affected by 5 factors:

Preload, Afterload, Inotropic state, HR and heart size

[1] Venous filling pressure (Preload) i.e. MSFP - RAP

During diastole, ventricle is very compliant so $\oplus\oplus$ preload $\rightarrow \oplus\oplus$ EDV $\rightarrow \oplus\oplus$ SV (Starling law) $\rightarrow \oplus\oplus$ COP

Factors $\oplus\oplus$ EDS

- 1 $\uparrow$ Atrial contraction
- 2 $\uparrow$ Total blood volume
- 3 $\uparrow$ Venous tone by symp. stim
- 4 $\uparrow$ Pumping by sk ms cont.
- 5 $\uparrow$ -ve intrathoracic p

Factors $--$ EDV

- 1 Standing
- 2 $\oplus\oplus$ intrapericardial p.
- 3 $--$ vent. compliance
e.g. myocardial infarction

[2] After load = Aortic & large arteries p (mean ABP)
End-systolic p. (ESP) nearly equals aortic p so it represents afterload

$\oplus\oplus$ Afterload $\rightarrow \oplus\oplus$ ESV $\rightarrow --$ SV (Starling law) $\rightarrow \ominus$ COP

So, cardiac output curve is shifted downward and to the Rt.

[3] Inotropic state of heart i.e. contractility

Contractility not dependent on pre or afterload i.e. intrinsic capacity.

$\uparrow$ +ve inotropic stimuli shift systolic pressure-volume curve upwards and shifts COP curves upwards & Lt & vice versa

Mechanism +ve inotropic $\rightarrow --$ ESV $\rightarrow \oplus\oplus$ SV $\rightarrow \oplus\oplus$ COP

Factors affecting inotropic state of whole heart (intrinsic)

[A] Intrinsic factors

[1] Force-Frequency relation $\oplus\oplus$ Frequency of contraction

increases contractility i.e +ve inotropic and vice versa

[2] Ischemia (↓ bl flow) produces -ve inotropic effect due to ↓ O_2 acidosis

[3] Chronic myocardial failure → -ve inotropic state.

B) Extrinsic Factors

[1] Activation of symp. adrenergic nerve → +ve inotropic

Mechanism Norepinephrine via β_1 receptors + cAMP which activates pln kinase A → phosphorylates voltage gated Ca^{++} channels

→ ++ opening time of Ca^{++} channels → accelerates systole

→ ++ active uptake of Ca^{++} by SR → " diastole

[2] Activation of parasymp (vagal) nerve → -ve inotropic

mainly on atrial muscle via acetylcholine.

[3] Xanthine e.g. caffeine -- breakdown of cAMP → +ve inotropic

[4] Glucagon ++ formation of cAMP

[5] Digitalis (cardiac glycosides) inhibits $Na^+-K^+ ATPase$

→ ++ intracell. Na^+ → inhibits Na^+/Ca exchanger

→ ++ intracell Ca^{++} → +ve inotropic

[6] Increased extracell Ca^{++} conc. +ve inotropic (not in sk ms)

[7] Ca^{++} antagonists (DHP) & antiarrhythmic drugs : -ve inotropic

N.B Heterometric autoregulation Homeometric autoregulation

Preload Regulation of COP by changing Inotropic state

[4] Heart rate affects COP in triphasic manner

[a] Changes in HR within physiological range 50-160/min

have little effect on COP; as it is connected by opposite changes in SV. This is because VR governs COP in normal heart

[b] At higher rates, COP ⊖ because of shortening of filling time

[c] At lower rates, COP ⊖ because SV is maximal and can't compensate for reduced HR below 50/min.

++ HR by symp. stim. as in exercise → -- duration of potential s systole → more time for filling → ++ COP
at HR 200/min because of ++ MSFP +ve inotropic effect.

4 Heart size (Hypertrophy)

2 types

a Eccentric (volume overload) b Concentric (pressure overload)

Trained athletes	e.g	Hypertension
Increased	EDV (H. size)	Constant
Mild thickening	Myocardium	Marked thickening
May over 35 L/min	COP	Less
Normal	Inotropic state	Heart failure if not ltt
		++ Lt vent. systolic p

Equilibrium between VR and COP

Equilibrium point occurs at intersection of VR curve & COP curve
i.e. $COP = VR$. At rest, 2 curves intersect at Rt atrial p 0-2 mmHg
Mechanism Starling law allows COP to equal VR.

Assessment of contractility by Ejection Fraction (EF)

Definition Fraction of EDV ejected each beat.

Measurement non invasively by cardiac ultrasound (ECHO)

Normally About 0.6 in a healthy heart

Factors affecting EF Contractility also filling p & aortic p

Significance Most important index of contractility

if below 0.5 suggests cardiac disease.

if below 0.3 is associated with high mortality.

Selected integrated responses

• Supine to erect posture Pooling of bl. in LL veins

-- MSFP → -- VR → -- COP → -- ABP

Compensated by reflex ++ HR, ++ contractility & ++ ABP
Both VR & COP curves shift upwards

Cardiac response to exercise

Many factors ++ COP up to 8 folds in maximal exercise in athletes. It results completely from symp. stim. → ++ HR & ++ contract.

A HR : HR is a good index of the degree of exercise. 150% of basal resting HR in mild 200% in moderate 250% in marked severe exercise.

$$\text{Maximal HR} = 220 - \text{Age in years}$$

Acceleration in HR during exercise is due to:

1. Vagal withdrawal
2. Increased sympathetic tone.
3. Activation of pulm. stretch receptors & muscle receptors
4. ++ circulating catecholamines.

B Ventricular function Symp. stim. & ++ catecholamines cause:

1. +ve inotropic effect shifts lt vent. p. vol. curve upwards & left
2. Shortening of ejection → ++ vent. relaxation & ++ Atrial cont.
3. In severe exhausting exercise (point D) the marked ++ HR is the main cause of ++ COP

VR and COP

1. In untrained normal subjects

- ⊖ During mild exercise, MSFP ++ by tensing abdom. & exercising m.
- ⊖ Then, muscle arterioles VD by metabolites & ++ symp. venous tone → ++ MSFP & VR

⊖ COP curve shifts upwards by symp stim. & -- TPR. COP is increased to 20 L/min.

2. In trained athletes e.g. long distance runner (marathon) Heart hypertrophy of volume overload so EDV ++ COP curves shift upward & COP ++ to 40 L/min in max. ex.

Cardiac work and O₂ consumption:

Heart 0.3% of body weight utilizes 7% of resting O₂ cons.

Difference between metabolism of cardiac & skeletal muscle

- 1 Heart energy 99% aerobic 1% anaerobic $\rightarrow$ $\rightarrow$ to 10% in exercise + afterload than
- 2 So, cardiac muscle has more blood supply, myoglobin & mitochondria (30% of C ms vol)
- 3 Cardiac ms has NO O_2 debt
- 4 Cardiac ms utilizes more substrates
FAT 60%, CHO 35% & ketone and aa 5%

Myocardial O_2 consumption MVO_2

TEC total chemical energy $\propto MVO_2$

Basal (non beating) MVO_2 2 ml & beating MVO_2 9 ml / 100g / min

N.B Since cardiac venous O_2 tension is low, increase in O_2 consumption requires increase in coronary blood flow.

Myocardial O_2 consumption is determined by:

- Systolic p. (wall tension)
- Shortening extent (stroke vol)
- Inotropic state contractility
- Heart rate.

Cardiac work Work output of heart

$$\text{Work} = \text{Load (P)} \times \text{Distance } (\Delta L)$$

$$\Delta L = EDV - ESV = SV$$

Systolic load is an index of afterload (P)

Work of Lt ventricle

$$= SV \times \text{mean aortic p}$$

Work of Rt ventricle

$$= SV \times \text{mean pulmonary p}$$

Energy converted to work each BEAT is STROKE work output.

Energy converted to work each MINUTE is MINUTE work output.

Forms of cardiac work output

1 Volume - pressure work or external work
 $= SV \times \text{Pressure}$

For Lt V 6 times that of Rt vent.

Used to move blood from low p. veins to high p. arteries

i.e Work performed by ventricle to raise p of blood each beat

++ afterload (pressure work) causes a greater increase in MVO_2 than ++ preload (volume work)

O_2 consumption/beat is determined by the area which represents:

a External work ejection loop plus

b Internal work triangle between systolic & diastolic curve.

It represents additional work output if vent. empty all its bl. content

2 Kinetic energy of blood 2% of total work.

Work used by heart to accelerate velocity of bl. in aorta & pulm.

Cardiac efficiency energy needed for mechanical work

Efficiency = $\frac{\text{Cardiac work/min}}{MVO_2}$ i.e. External or effective work

MVO_2 represents total energy (determined by SV, HR, systolic P, cont.)

Normally, Maximal 20-25% In heart failure 5-10%

Cardiac reserve CR

Definition Maximum % COP can increase above normal

Normal young adult : up to 300-400%

Athletic trained person : 600%

Elderly : 200%

Heart failure : 0%

Involves 1 Factors ++ preload (EDV) 2 Factors -- afterload (aortic p)
3 +ve inotropic stimulants 4 +ve chronotropic stimulants
5 Hypertrophy

Diseases that -- CR 1 Ischemic heart disease.

2 Myocardium damage (infarction) 3 Valvular heart disease.

Diagnosis of low CR (Exercise test)

Method: Treadmill or walking up & down steps

In low CR COP fails to maintain body activity.

Test is cutoff if ① Shortness of breath (dyspnea)

- (2) Muscle fatigue resulting from muscle ischemia.
- (3) Maximal increase in HR ($220 - \text{Age in years}$)

Heart Failure

Definition: Failure of heart to pump enough blood to satisfy body needs.

Manifestations:

- **Forward** : -- COP
- **Backwards** : Lt ventricle pulmonary congestion
Rt ventricle systemic congestion

Causes :

- 1 **Systolic dysfunction** e.g. myocardial infarction $\rightarrow$ inefficient cont.
- 2 **Diastolic dysfunction** e.g. hypertension $\rightarrow$ -- diastolic compliance

In both cases, EF is low down to 20%.

Response to -- COP in HR :

- 1 ++ symp. discharge.
- 2 ++ circulating catecholamines.
- 3 ++ afterload $\rightarrow$ more -- in COP.
- 4 VC of renal vessels $\rightarrow$ Na^+ & H_2O retention.
- 5 ++ renin $\rightarrow$ ++ angiotensin II $\rightarrow$ more VC
- 6 ++ aldosterone $\rightarrow$ more Na^+ & H_2O retention.
- 7 ++ ANP due to ++ RAP $\rightarrow$ Na^+ & H_2O excretion (escape phenomenon)
- 8 Visceral congestion

Edema is due to end organ unresponsiveness to ANP.

ttt 1 +ve inotropic e.g. digoxin

2 Diuretics $\rightarrow$ -- preload.

3 Arteriolar vasodilation $\rightarrow$ -- afterload

4 ACE inhibitor $\rightarrow$ -- Angiotensin II $\rightarrow$ -- afterload
 $\rightarrow$ -- Aldosterone $\rightarrow$ -- preload

Cardio v

2012/08/25